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Muon Radiography for Non-Destructive, Non-Invasive Assay and Long-Term Monitoring of Nuclear Fuel Debris and Fuel Assemblies

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We propose developing a muon cosmic ray radiography system dedicated to the task of assay and long-term safeguard monitoring of Fukushima fuel debris or fuel assemblies. The system would be non-destructive and non-invasive, using naturally occurring cosmic radiation to assay the entire volume of the fuel debris container. The technique distinguishes between materials and is especially sensitive to measuring the location and amount of heavy elements such as uranium and plutonium. Scope of the feasibility study would encompass a) demonstrating material assay (location and amount) of a regular-shaped depleted uranium object sealed in a debris container, and b) repeating the material assay of debris-proxy materials of irregular shape (corium), sealed in a debris container. Muon radiography of each container would result in a unique “fingerprint” of the contents, useful for long-term safeguards monitoring.

The Fukushima Daiichi clean-up will result in storage and processing of as much as 300 tons of fuel debris. This debris will be cataloged, and reside in canisters in long-term storage. The proposed muon radiography technique is the only way of monitoring the contents of the canisters which combines the following features:

- non-destructive,
- non-invasive,
- inspects the entire volume (not just the debris surface),
- measures the shape and amount of debris, and
- is suitable for long-term, cost-effective safeguards monitoring.

Current non-destructive assay techniques include radiography with x-rays, which are not as penetrating as muons and therefore not suited to assay of the entire debris volume. An alternative to muon scattering radiography is muon transmission radiography, but it does not provide material assay identification and has inferior position resolution. Other potential techniques involve radiation detectors, which have very limited imaging and volumetric assay capabilities.

Approach:

- Use a small (~1-m x 1-m) muon radiography system to:

- Perform assay study (measure material shape and mass) inside a facsimile debris container of a known, regular-shape depleted uranium object (10-cm cube)
- Obtain/construct irregular shape objects as proxies for fuel debris
- Repeat assay study of “fuel debris” objects (possibly DU fuel rods, or irregular-shaped objects)
- Build simulation model in GEANT4 to confirm and explore results
- Questions answered and results:
 - Demonstration of basic feasibility of muon technique applied to fuel debris
 - Establish technique capabilities, such as ability to measure minimum size and mass of debris

Impact:

Successful project would likely result in:

- Adoption of technique by the Fukushima Daiichi remediation project for assay and long-term monitoring of debris; resulting in construction of many muon systems to be part of the debris removal and storage process
- Improved public confidence in the ability to monitor and safeguard fuel debris
- Establish a new international standard measurement technique, perhaps certified by IAEA

Risks:

Primary risk is developing realistic fuel debris proxy objects and working through the approval process required to study them in the laboratory. Greater realism would pose greater difficulty (material handling, radiation safety, etc.), but also provide a more convincing result. For example, it may be easier to obtain and study depleted uranium fuel rods than it would be to obtain actual fuel debris – though studying both materials would be desirable.

There are potential risks and complications for the ultimate acceptance and site implementation of the technique, associated with logistics and politics of international collaboration involving several organizations with different agendas (DoE/US, TEPCO/Japan, IAEA, etc.). This “political/logistical” risk would be minimal for the proposed feasibility study.